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**SUBMISSION OF SUBSTITUTE SPECIFICATION**

Sir:

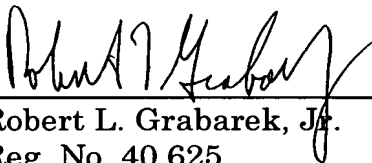
Attached is a Substitute Specification and a marked-up copy of the original specification. I certify that said substitute specification contains no new matter and includes the changes indicated in the marked-up copy of the original specification.

Respectfully submitted,

CROWELL & MORING LLP

Dated: March 21, 2006

By



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**METHOD FOR MANUFACTURING COMPONENTS**

**[0001]** This application claims the priority of International Application No. PCT/DE2004/001872, filed August 24, 2004, and German Patent Document No. 103 43 782.7, filed September 22, 2003, the disclosures of which are expressly incorporated by reference herein.

**BACKGROUND AND SUMMARY OF THE INVENTION**

**[0002]** The invention relates to a method for manufacturing components, preferably of a gas turbine.

**[0003]** Modern gas turbines, especially aircraft engines, must meet extremely high demands with regard to reliability, weight, performance, service life and economic factors. In the last 10 years, aircraft engines that fully meet the above requirements and have achieved a high measure of technical perfection have been developed, especially in the civilian sector. In the development of aircraft engines, the choice of materials and the search for suitable new materials as well as new manufacturing methods play a crucial role.

**[0004]** The most important materials used today for aircraft or other gas turbines are titanium alloys, nickel alloys (also known as superalloys) and high-strength steels. The high-strength steels are used for shaft parts, transmission parts, compressor housings and turbine housings. Titanium alloys are typical materials for compressor parts. Nickel alloys are suitable for the hot parts of an aircraft engine.

**[0005]** In the manufacture and/or production of precision components made of metallic or ceramic powders, powder injection molding has proven especially successful. Powder injection molding is related to injection molding of plastics and is also known as the metal injection molding method (MIM method). With the powder metallurgy molding method, it is possible to produce components that achieve almost full density and approx. 95% of the static strength of forged

parts. The reduced dynamic strength in comparison with forged parts can be compensated through a suitable choice of materials.

**[0006]** In the metal injection molding method according to the state of the art, the rough features of the process include mixing a powder, preferably a metal powder, a hard metal powder or ceramic powder with a binder and optionally a plastifier to form a homogenous mass in a first process step. From this homogeneous mass, molded articles are produced by injection molding. Injection-molded articles already have the geometric shape of the component to be manufactured, but their volume is larger due to the volume of the added binder and the plastifier. In a debinding process, the binder and plastifier are removed from the injection-molded articles. Then during sintering, the molded article is compacted and/or shrunk to form the finished component. During sintering, the volume of the molded article decreases; it is important for the dimensions of the molding to shrink uniformly in all three directions. Volume shrinkage amounts to between 30% and 60%, depending on the binder content and plastifier content.

**[0007]** According to the state of the art, the usual procedure in powder injection molding is to first subject each molding individually to the debinding process and then to sinter each molding individually. If necessary, several components manufactured by powder injection molding are joined together by suitable joining methods only after the actual metal injection molding. Thus the production of components having a complex three-dimensional shape is possible only to a limited extent by the powder injection molding method known from the state of the art.

**[0008]** Against this background, the object of the present invention is to propose a novel method for manufacturing components.

**[0009]** According to this invention, several molded articles are joined together by a diffusion process during sintering to produce a component.

**[0010]** In the sense of the present invention, it is provided that in order to manufacture a component from multiple molded articles, the molded articles shall be joined together by a diffusion process to form the component that is to be produced and this takes place during sintering, i.e., during the powder injection molding process. This makes it possible to manufacture even components having a complex three-dimensional shape and to do so rapidly and inexpensively with the help of the powder injection molding process.

**[0011]** According to an advantageous refinement of the present invention, the molded articles to be joined together are brought into surface contact, preferably into a form-fitting surface contact, at sections of the molded articles that are to be joined together and this is done at least during sintering, where a pressure is applied to the molded articles to be joined together during sintering and during the diffusion process which takes place concurrently.

**[0012]** The inventive method is used in particular for manufacturing blades or blade segments of multiple blades of an aircraft engine, where these blades or blade segments are made of a nickel-based alloy or a titanium-based alloy.

**[0013]** Preferred refinements of the present invention are derived from the following description.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0014]** Exemplary embodiments of the present invention are explained in greater detail on the basis of the drawings without being limited to these embodiments. The drawings show:

**[0015]** Figure 1 is a block diagram to illustrate the individual process steps in powder injection molding;

**[0016]** Figure 2 is a cross section through two molded articles to be joined together with the help of the inventive method;

**[0017]** Figure 3 is another cross section through two molded articles to be joined together with the help of the inventive method; and

**[0018]** Figure 4 is another cross section through two molded articles to be joined together with the help of the inventive method.

## DETAILED DESCRIPTION OF THE DRAWINGS

**[0019]** The present invention relates to the production of components, preferably of a gas turbine, in particular of an aircraft engine, by powder injection molding (PIM). Powder injection molding is also known as metal injection molding (MIM).

**[0020]** With reference to Figure 1, the individual process steps of the powder injection molding process are explained in greater detail. In a first step 10, a metal powder, a hard metal powder or a ceramic powder is supplied. In a second step 11, a binder and optionally a plastifier are supplied. The metal powder supplied in process step 10 and the binder and plastifier supplied in process step 11 are combined in process step 12 to form a homogeneous mass. The amount of metal powder by volume in the homogeneous mass is preferably between 40% and 70%. The amount of binder and plastifier by weight in the homogeneous mass thus varies approximately between 30% and 60%.

**[0021]** This homogeneous mass of metal powder, binder and plastifier is processed further by injection molding in the sense of step 13. Molded articles are produced by injection molding. These molded articles already have all the typical features of the components to be manufactured. In particular, the molded articles have the geometric shape of the component to be manufactured. However, they have a larger volume due to the binder content and the plastifier content.

**[0022]** In the downstream step 14, the binder and the plastifier are expelled from the molded articles. Process step 14 may also be referred to as a debinding process. The expulsion of binder and plastifier may be accomplished in various

ways. It is usually done by fractional thermal decomposition, i.e., vaporization. Another possibility is to remove the thermally liquefied binder and plastifier by suction through capillary forces, by sublimation or through the use of solvents.

**[0023]** Following the debinding process in the sense of step 14, the molded articles are sintered in the sense of step 15. During sintering, the molded articles are compacted to form the components having the final geometric properties. During sintering, the molded articles thus undergo a reduction in size, wherein the dimensions of the molded articles must shrink uniformly in all three directions. The linear shrinkage is between 10% and 20%, depending on the binder content and plastifier content.

**[0024]** After sintering, the finished component is obtained, as represented by step 16 in Figure 1. If necessary, after sintering the component (step 15), it may also be subjected to a finishing process in the sense of step 17. However, the finishing process is optional. A component ready for installation may also be obtained immediately after sintering.

**[0025]** It is within the scope of the present invention to manufacture a component with the help of the powder injection molding process by forming the component from multiple molded articles, where the components are joined together by a diffusion process during the powder metallurgy injection molding process. Thus, for example, the component to be manufactured may be assembled from two molded articles, which are joined together by the diffusion process during sintering. It is also possible to join a larger number of molded articles together to form a component during sintering.

**[0026]** To join the molded articles in the manufacture of the component, the molded articles are brought into surface contact at sections and/or surface areas of the same that are to be joined together. This means that the molded articles to be joined together are in contact with one another at the sections and/or surface areas. During the diffusion process, a pressure is exerted on the molded articles coming in contact or the sections of the molded articles coming in contact. The surface contact between the molded articles that are to be joined

together and the application of pressure to the same take place at least during the sintering process. The diffusion process thus takes place during sintering.

**[0027]** It is also possible to establish the surface contact and the pressure on the molded articles that are in contact and are to be joined together even during a presintering and/or during the debinding process. The procedure is preferably such that surface contact is already established during the debinding process and during presintering and also during the actual sintering but the pressure is exerted on the molded articles only during the actual sintering. For the sake of thoroughness, it should be pointed out here that the presintering takes place between the debinding process and the actual sintering, but during presintering there is not yet any mentionable shrinkage of the molded articles to be joined together.

**[0028]** According to an advantageous refinement of the inventive method, the molded articles are brought into form-fitting surface contact. This is explained on the basis of Figures 2 through 4 as follows.

**[0029]** Figure 2 shows two molded articles 18 and 19 to be joined together by a diffusion process during powder injection molding. The molded articles 18 and 19 come in contact with one another at sections and/or surface areas 20 and 21. As Figure 2 shows, the surface area 20 of the molded article 18 is designed with a wedge-shaped cross section. This wedge-shaped surface area 20 of the molded article 18 enters into a form-fitting engagement with the surface area 21 of the molded article 19 having a corresponding design. The surface area 21 of the molded article 19 thus forms a wedge-shaped groove in cross section.

**[0030]** Figure 3 illustrate an alternative embodiment of two molded articles 22 and 23 that are to be joined together. Again in the exemplary embodiment according to Figure 3, surface areas 24 and 25 of the molded articles 22 and 23 that are to be joined together are in form-fitting contact. To this end, a protrusion having a trapezoidal cross section is formed on the surface area 25 of the molded article 23, engaging in a recess having a corresponding design in the surface area 24 of the molded article 22.

**[0031]** Figure 4 shows another possible embodiment of two molded articles 26 and 27 that are to be joined together. In the embodiment of Figure 4, surface areas 28 and 29 of the two molded articles 26 and 27 that are to be joined together are in turn brought into form-fitting contact with one another. In contrast with the exemplary embodiment according to Figure 3, the protrusion and/or recess in the exemplary embodiment according to Figure 4 do/does not have a trapezoidal cross section in the area of the sections and/or the surface areas 28 and/or 29 but instead have a rectangular cross section. In the exemplary embodiments according to Figures 2 and 3, the molded articles 18 and 19 and/or 22 and 23 that are to be joined together are arranged laterally side by side; in the exemplary embodiment in Figure 4, the molded articles 26 and 27 are positioned one above the other.

**[0032]** The form-fitting connection between the molded articles to be joined together by the diffusion process during sintering improves the dimensional stability of the component to be manufactured.

**[0033]** It should be pointed out here that the molded articles to be joined together in the sense of the present invention may be designed identically with regard to their material composition and/or their shrinkage properties and they may also have different properties in this regard. If the material compositions and the shrinkage properties of the molded articles to be joined together are identical, then a uniform shrinkage occurs for the molded articles to be joined together during the sintering process.

**[0034]** However, molded articles having different shrinkage properties in the sense of the present invention may also be joined together by the diffusion process during sintering. It is also within the scope of the present invention to sinter a molded article that has a greater sintering shrinkage onto a molded article having less shrinkage. In the exemplary embodiments illustrated in Figures 2 through 4, this would mean that molded articles 19, 22 and 26 have a greater shrinkage and thus shrink to a greater extent than molded articles 18, 23 and/or 27.



**[0035]** Molded articles having different shrinkage properties can be provided by using molded articles made of different material compositions. For example, molded articles produced from different metal powders and therefore different metal alloys may be used. If molded articles made of different metal powders are to be joined together, it is important to be sure that the sintering temperature and/or diffusion temperature of the metal powders are of the same order of magnitude, so that the shrinkage of the molded articles will also occur simultaneously. The material composition for producing molded articles having different shrinkage properties may also be modified by varying the type and extent of the binder used. In addition, different shrinkage properties can also be achieved with the same material composition by performing different presintering operations on molded articles having the same material composition.

**[0036]** Another alternative of the present invention is to compensate for the different shrinkage properties when using molded articles having different shrinkage properties by processing the molded articles by means of an upstream presintering process prior to the actual sintering. The different shrinkage properties of the molded articles to be joined together may be compensated in such a way that the shrinkage properties of the molded article are coordinated during the actual sintering process.

**[0037]** According to another alternative of the inventive method, the different shrinkage properties can be compensated by the fact that the molded articles, which are made of different metal powders, for example, also differ with regard to their binders and optionally their plastifiers and/or their content of metal powders, binders and optionally plastifiers. Then even when molded articles made of different powders are joined together, for example, the difference in shrinkage properties can be compensated. However, here again, it is important to be sure that the sintering temperature and diffusion temperature of the material compositions of the molded articles are of the same order of magnitude, so that the shrinkage of the molded articles will also proceed at the same time.

**[0038]** With the help of the present invention, it is now possible to join powder metallurgical molded articles directly together during sintering. This creates new design options for components that are to be manufactured by powder metallurgy. In addition, this eliminates the separate joining and connecting operations that are required after the actual powder injection molding in the state of the art. Due to the elimination of this extra step, which is obligatory in the state of the art, the components can be manufactured much more rapidly and less expensively.

**[0039]** To reinforce the diffusion effect in sintering the molded articles that are to be joined together, the surfaces of the same that come in contact may have a coating. This coating then forms a so-called sintering aid, which can be applied as a film or as a slip layer or material to the surface areas of the molded articles to be brought into surface contact. This coating, which increases the diffusion effect, can be applied to at least one of the surface areas and/or sections to be joined together or to both or to all sections to be joined together.

**[0040]** To increase the diffusion effect in sintering, the sintering may also be performed under a special gas atmosphere, which supports the diffusion effect.

**[0041]** The inventive method is especially suitable for producing components for a gas turbine, in particular an aircraft engine. It is thus within the scope of the present invention to manufacture blades or blade segments or rotors having integral blading – so-called blisks (bladed disks) or blings (bladed rings) – of a gas turbine with the help of the inventive method. In addition, sealing parts, adjusting levers, securing parts or other components having a complex three-dimensional shape can also be manufactured by the inventive method. Such components for a gas turbine consist in particular of a nickel-based alloy or a titanium-based alloy. However, the inventive method is not limited to the manufacture of components for gas turbines. Essentially components for the automotive field, general mechanical engineering or other application areas may also be manufactured by this method.